CO profile retrieved from combined TES and MLS measurements on Aura satellite

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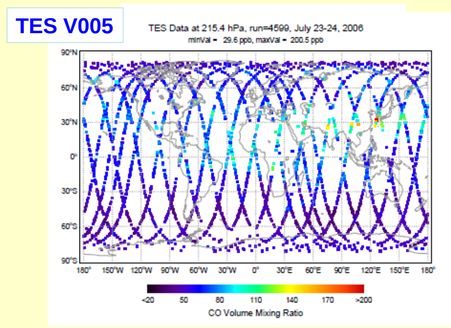
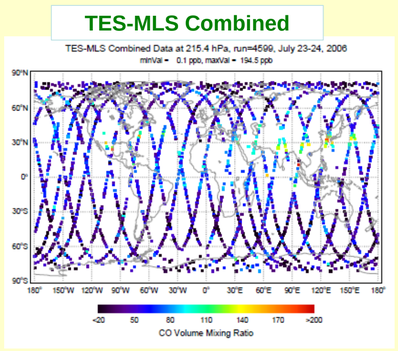
Abstract

Carbon monoxide (CO) is an important tracer in studies of pollution sources, air quality, and atmospheric transport and chemistry. CO is one of the major precursors for tropospheric ozone production. Its distributions in the upper-troposphere / lower-stratosphere (UTLS) provide very useful information in studies of UTLS exchange mechanisms. However, satellite remote sensing observations of CO by an individual instrument are limited in sensitivity either in the troposphere or above tropopause. For example, the nadir radiance measurements by the Tropospheric Emission Spectrometer instrument (TES) on NASA's Aura satellite launched July 2004 are used to derive CO profiles with maximum retrieval sensitivity in the mid-troposphere; the limb radiance measurements by the Microwave Limb Sounder (MLS) instruments, also aboard Aura, are used to derive CO profiles at and above upper-troposphere. Here we present a new Aura CO data product which is derived from combining TES and MLS measurements. The new CO profiles cover the entire atmosphere with much improved vertical sensitivity over the two stand-alone products in the UTLS region. For example, comparing to TES CO profile with degree of freedom for signal (DOFS) of less than 2, the Aura CO profile has DOFS of 2-4 in altitude below 50 hPa. We present the retrieval algorithm and results. Preliminary data validation comparing the new Aura product to the in-situ aircraft and balloon CO measurements will be presented.

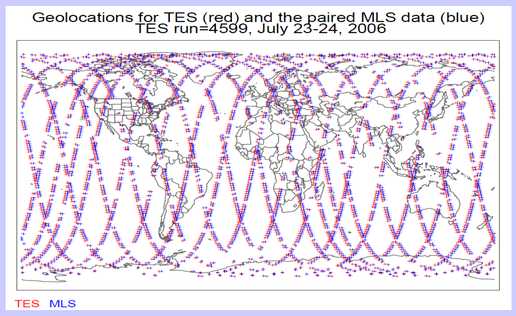


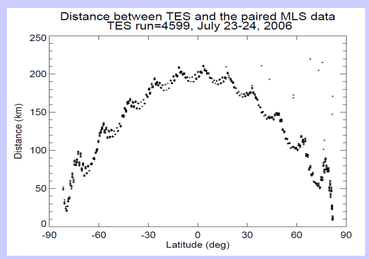
Example: CO Volume Mixing Ratio at 215 hPa, July 23-24, 2006

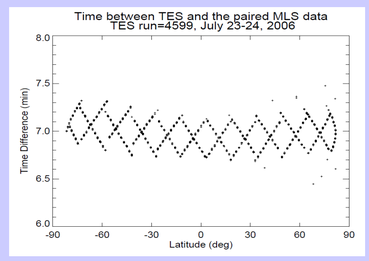


TES-MLS Data Match

- Combined-product file granule:
  Per TES Global Survey (16 orbits, ~26 hrs)
- Data matching:
  - Good QA for TES and MLS CO.
  - Time diff: 7± 0.3 min.
  - Distance: 60 – 220 km.







Algorithms

$$x^{i+1} = x^i + \hat{S}_t\left[K_{TES}^T S_{y\_TES}^{-1}\left(y_{TES} - FM_{TES}(x^i)\right) + K_{MLS}^T S_{y\_MLS}^{-1}\left(y_{MLS} - FM_{MLS}(x^i)\right) + S_a^{-1}\left(x_a - x^i\right)\right]$$

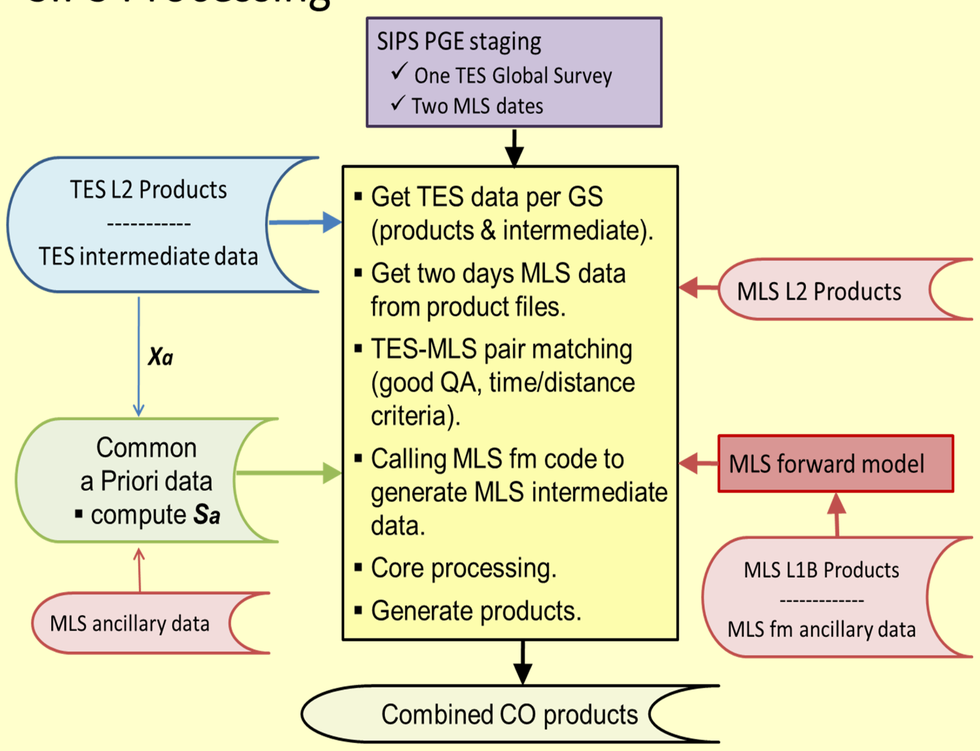
The total error and averaging kernel:

$$\hat{S}_t = \left(K_{TES}^{\ T} S_{y\_TES}^{\ -1} K_{TES} + K_{MLS}^{\ T} S_{y\_MLS}^{\ -1} K_{MLS} + S_a^{\ -1}\right)^{-1}$$

$$A = \hat{S}_t\left(K_{TES}^{\ T} S_{y\_TES}^{\ -1} K_{TES} + K_{MLS}^{\ T} S_{y\_MLS}^{\ -1} K_{MLS}\right)$$

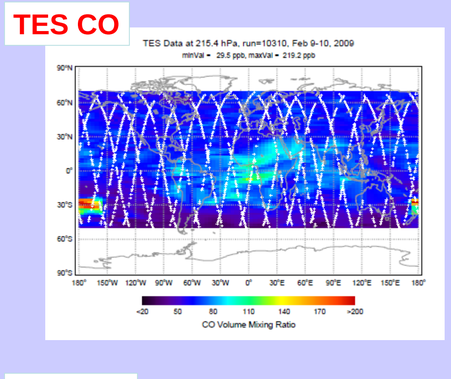
- For a given matched locations, measured radiances from TES and MLS are jointly used to retrieve a single 'Aura CO' profile along with other interfering species profiles.
- Needed TES terms are pre-stored, *e.g.*, a term involving radiance residuals, Jacobian, and measurement errors.
- The MLS callable forward model will be executed with initial CO profile (*e.g.*, TES a priori) and other species to obtain spectral radiances and Jacobians.
- The 'Aura CO' product will consist retrieved CO profiles, the retrieval errors and the averaging kernels.

SIPS Processing



Example: One Global Survey

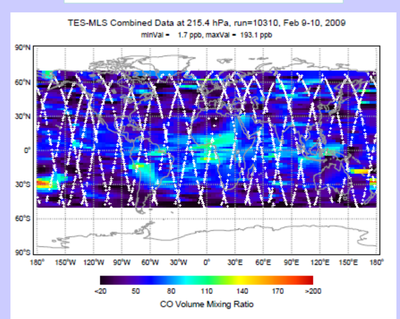
(the 'black Saturday' describing the Australia fires, early Feb 2009)

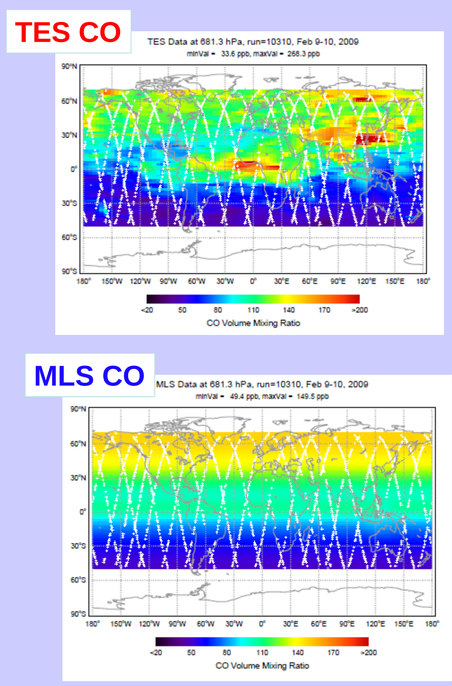


Comparing TES, MLS, and Combined CO Products :

CO VMR at 215 hPa, Feb9-10, 2009

TES-MLS Combined CO

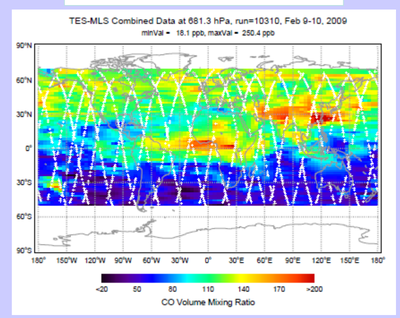




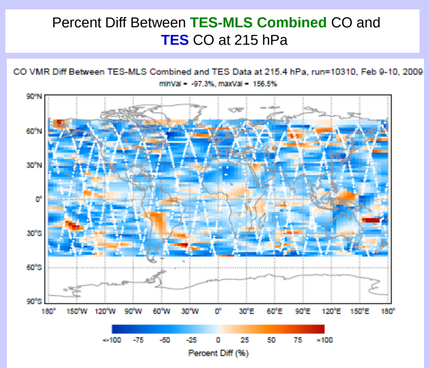
Comparing TES, MLS, and Combined CO Products :

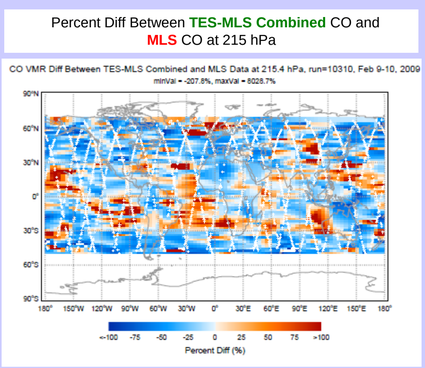
CO VMR at 681 hPa, Feb9-10, 2009

TES-MLS Combined CO



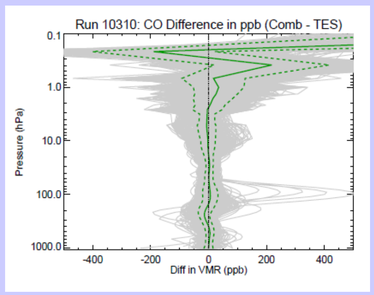
Percent differences between the combined and the original TES/MLS CO VMR at 215 hPa.

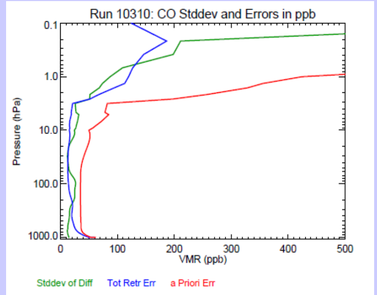


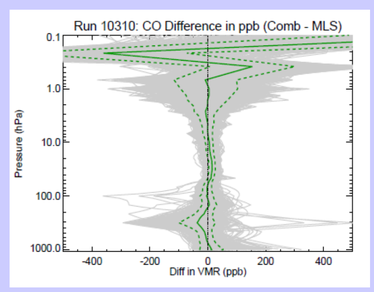


Example: One Global Survey (Cont.)

Statistics: Diff between combined CO and TES or MLS respectively, in ppb, and comparing to retrieval errors.







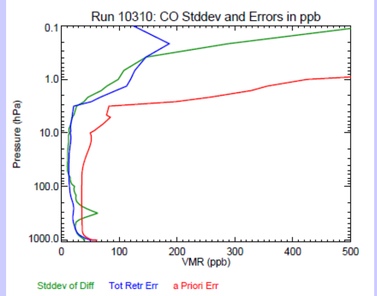
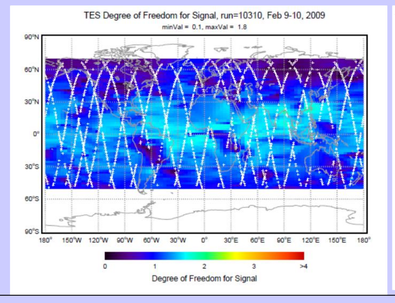
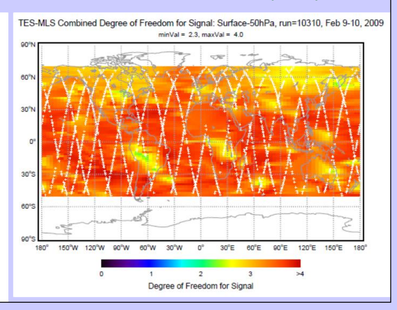


Illustration of prototyping results:
Degree of Freedom for Signal (DOFS) of CO, Feb9-10, 2009

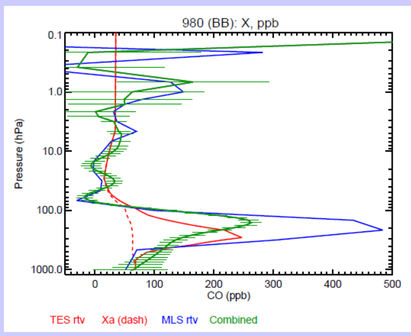
TES Total DOFS (**< 2**)



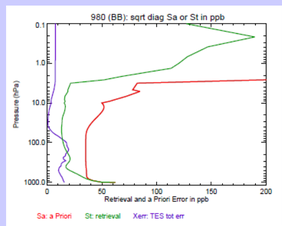
TES-MLS Combined DOFS Surface – 50hPa (**2-4**)



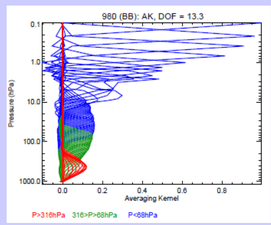
CO Profile Retrieval Example:
Australia Bushfire Plum Scene



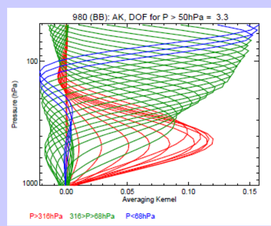
Errors



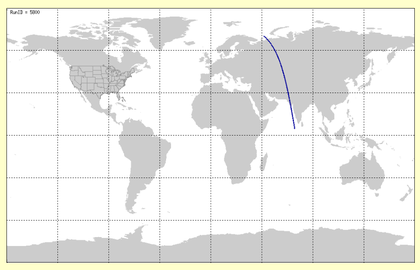
AK, DOFS=12.7



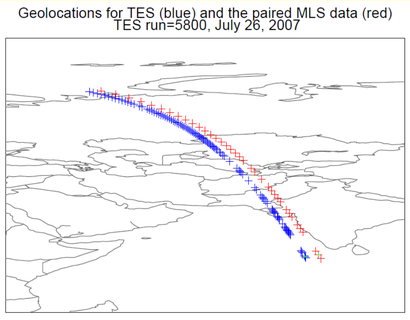
AK, surf – 50hPa, DOFS = 3.2



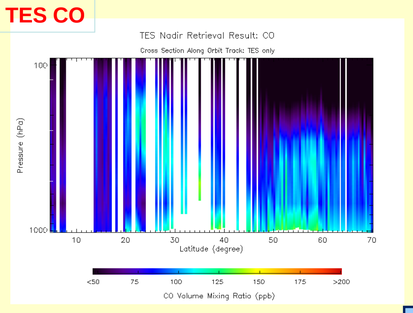
Example: TES Special Observation (Step & Stares)



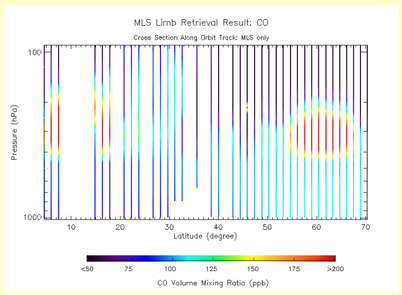
Geolocations for TES (blue) and the paired MLS data (red)
TES run=5800, July 26, 2007



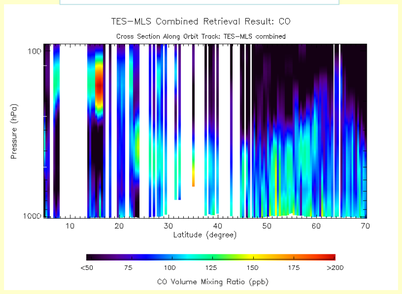
TES CO



MLS CO



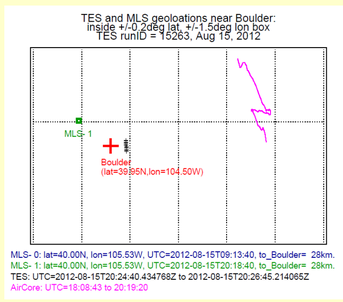
TES-MLS Combined CO

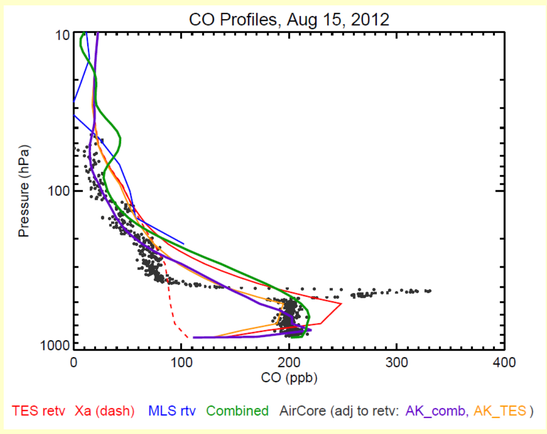


The MLS measurements contribute to the CO profile retrieval above ~316 hPa. In the lower-mid troposphere, Aura CO are very similar to TES CO distributions.

Validation with AirCore Balloon Measurements

TES/MLS team collaborate with the NOAA AirCore team to schedule balloon launches near Boulder in coincidence with Aura overpasses. The results shown are for Aug 15, 2012 observations and the comparisons between AirCore and Aura CO profiles.



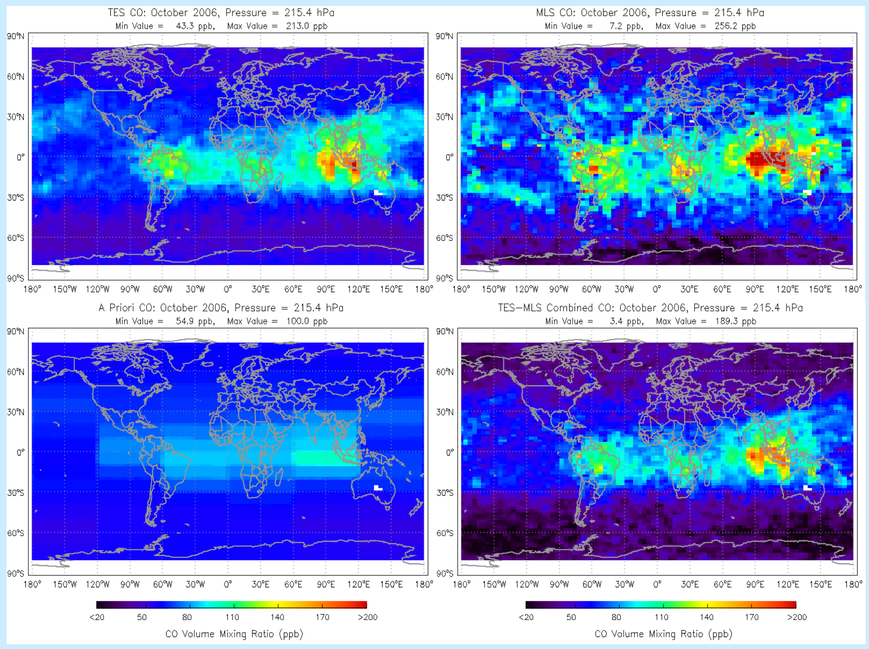


NOAA AirCore team:

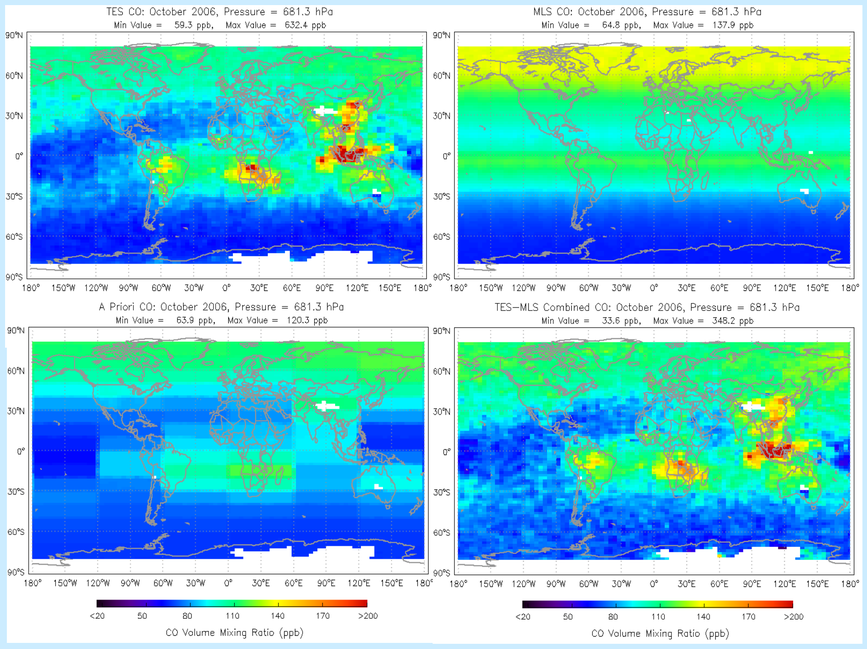
Example: Monthly Averages for October 2006

One month GS data (Oct 2006) are processed to obtain TES-MLS combined CO profiles. The monthly averages of TES, MLS, and the combined Aura CO VMRs are presented at 215 hPa and 681 hPa. The *a priori* fields are also shown. In the lower troposphere (681 hPa), the combined CO global distribution is very similar to that of TES showing enhancements due to fires over Indonesia, S America, and SC Africa, and pollutions over China. In the upper troposphere (215 hPa), the combined CO distribution retain the similar features shown on TES and MLS CO fields.

Monthly Averages: Oct 2006, Pressure = 215.4 hPa



Monthly Averages: Oct 2006, Pressure = 681.3 hPa



Summary

- TES and MLS standalone CO profile retrievals are sensitive respectively to lower-mid troposphere and upper troposphere and above. Measurements and the forward models from the two instruments are used jointly to optimally retrieve an Aura CO profile product.
- TES Global Survey nadir and MLS limb tangent locations are paired within 6-8 min and less than 220 km.
- The combined CO profiles have increased vertical sensitivity from mid-troposphere to lower stratosphere, e.g., compared to TES DOFS of <2, the combined CO DOFS will be 2-4 between surface and 50 hPa.
- The new Aura CO product will be at TES GS granule and be processed at TES/MLS SIPS.

Aura CO Data	
VolumeMixingRatioProfile	TESUTCTime
Pressure	TESDayNightFlag
TotalError	Latitude
TotalErrorCovariance	Longitude
AveragingKernel	MLSLatitude
DegreesOfFreedomForSignal	MLSLongitude
SpeciesRetrievalQuality	MLSTime
TotalColumnDensity	Time
TotalColumnDensityError	ProfileDistance
TESConstraintVector	Sequence
TESVMRProfile	Scan
TESAltitude	